Routing in Multi-Technologies Wireless Sensor Networks

Brandon Foubert
Self-Organizing Future Ubiquitous Networks Group
Inria - Lille, France
brandon.foubert@inria.fr

Abstract

Wireless Sensor Networks (WSN) are constrained by their Radio Access Technologies' (RAT) capabilities. In Multiple Technologies Network (MTN) nodes are able to use several RAT in a multi-hop scheme. The routing and RAT selection is handled by the nodes with dedicated protocols. In this article, we present our current work and future plans for a Routing Over Different Existing Network Technologies (RODENT) protocol designed for MTN. It enables dynamic (re)selection of the best route and RAT based on the data type and requirements. RODENT is based on a multi-criteria route selection via a custom lightweight TOPSIS method. We have implemented a functional prototype on Pycom FiPy devices. RODENT increases flexibility, coverage and energy savings while supporting multiple data requirements.

1 Introduction

Wireless Sensor Networks (WSN) enable a remote monitoring of various metrics and many more use cases [4]. Such networks usually rely on a single medium distance Radio Access Technology (RAT) (*e.g.,* IEEE 802.15.4). Deployments are constrained by the limits of the chosen RAT, in terms of coverage and throughput. Some RAT are even so constrained that they may not be able to comply with specific data requirements such as delay-intolerant data. Additionally, outdoor nodes have to bear the weather changes (*e.g.,* rain) which impacts the communication quality.

Many different RAT are available for WSN nowadays [2]. Different RAT come with different performances and capabilities. Multiple Technologies Networks (MTN) can overcome the aforementioned issues [1]. With several RAT built-in, the nodes' range of deployment is extended, as nodes' can switch RAT and relay data through multi-hop. Nodes that have several data requirements (*e.g.,* temperature and video monitoring) can use several path accordingly.

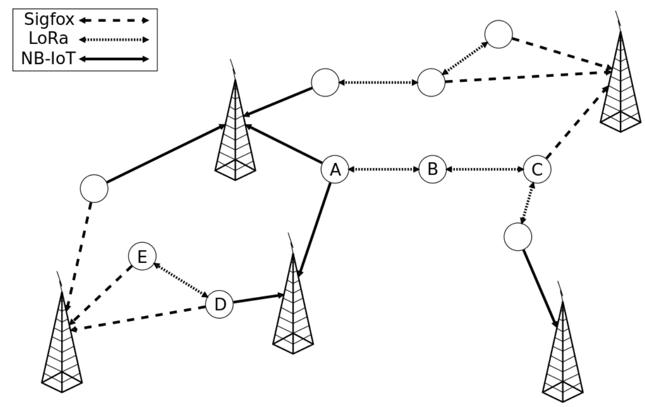

Figure 1. MTN example.

Table 1. Example link matrix LM_D.

	Energy	*Money*	*Bit-rate*
Sigfox BS	12	102	22
NB-IoT BS	151	87	174
Node E (LoRa)	37	0	72

Currently available routing protocols are not suited for MTN. Thus we conceived a novel Routing Over Different Existing Network Technologies protocol (RODENT) designed for MTN. Our contribution takes account of every nodes' RAT for the route selection. Nodes select the best route from the set of known routes by means of a customized Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method [3]. Criteria for the best route depend on the use case and the requirements data has to meet (*e.g.,* data size, deadline).

RODENT is implemented and we assessed its performances through experimental evaluation on an MTN prototype composed of Pycom FiPy devices featuring multiple RAT. Results show that RODENT increase network flexibility and reliability, decrease energy consumption and enable better consideration of the data requirements while maintaining a good packet delivery ratio.

2 Routing overview

The distinctive feature of RODENT is to enable multi-RAT routes. Each route has different cost and performances. This Section offers an overview on RODENT's operations.

Let's consider the operations of *ND* and *NE* from Figure 1 as example. ND boots without any knowledge of its surroundings. ND's link layer scans the environment with every RAT and builds its link matrix LM_D in Table 1. Each link is associated to a neighbor and a RAT. Based on LM_D the network layer starts to build the route matrix RM_D. The link from ND to the base stations are registered in RM_D as single-hop routes. NE meanwhile does the same, and selects its only available route toward the Sigfox base-station. NE advertises its route which is received by ND through their LoRa link. ND constructs its third route by adding the route's and LoRa link's costs. RM_D is then similar to Table 2. ND then selects a best route for each of its RV. The selection is made independently of the RAT and based only on the routes' costs and performances. In this case and considering Table 3, the best route for $RV_{monitoring}$ is the one toward the Sigfox base station because low energy consumption is favored. The best route for RV_{alarm} is the one toward the NB-IoT base station because high bit-rate is favored. ND then starts to advertise and use its best routes.

3 Selection method

In MTN a single node owns several RAT. This hardens the route selection as nodes must consider many routes over many RAT. In this Section, we present a sketch of the selection method used by RODENT to chose the best route.

The selection has to be based on multiple criteria *e.g.,* the energy consumption, delay etc. of each route. Several tools are available in the literature for multi-criteria decision, such as utility and cost functions, Markov chains, fuzzy logic, game theory, data mining and Dempster-Shafer theory. We found the Multiple Attribute Decision Making (MADM) methods to be the most fitting for route selection.

MADM methods formalize the problem as a decision matrix. The matrix is composed of the candidates and the attributes considered for the ranking. Each candidate has a set of attribute's values that reflects its performance. An MADM method takes the decision matrix as input and outputs a ranking of all the candidates. Several MADM methods are available in the literature, such as Simple Additive Weighting (SAW), Weighting Product (WP), Analytical Hierarchy Process (AHP) and Gray Relational Analysis (GRA). Among those methods, we find the most interesting to be Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). TOPSIS compares each candidate based not only on its closeness to the best theoretical candidate but also on its distance from the worst theoretical candidate.

TOPSIS however suffers from rank reversal and a complex ranking computation algorithm. Several works tries to tackle the rank reversal issue, but at the expense of an increased complexity. In a previous work, we designed a lightweight TOPSIS for hardware-constrained devices which avoid rank reversal [3]. We leverage this lightweight TOPSIS method to perform the route selection in RODENT.

We refer to the route matrix of node x as RM_x. For route selection, RM_x is composed of all the routes available for node x. RM_x's attributes are relative to the routes *e.g.,* the number of hops and the total energy consumption. For example, ND in Figure 1 could have a route matrix RM_D such as the one in Table 2. TOPSIS takes as input a set of weights for

Table 2. Example route matrix RM_D.

	Energy	*Money*	*Bit-rate*	*Hops*
Sigfox BS	12	102	22	1
NB-IoT BS	151	87	174	1
Node E (LoRa)	49	102	94	2

Table 3. Requirements vectors.

	Energy	Money	Bit-rate
$RV_{monitoring}$	0.6	0.3	0.1
RV_{alarm}	0.1	0.1	0.8

each attribute. The weights represent the importance of each attribute in the ranking process. We refer to a set of weights as a Requirements Vector (RV). RV_x is the requirements vector for use case x *e.g.,* $RV_{monitoring}$. For route selection RV's values are set based on the data requirements that the node have to meet *e.g.,* prioritize speed over energy consumption, and such that $RV\{e_n \in RV \mid \sum_{n=1}^{|RV|} e_n = 1\}$. Examples requirements vectors are depicted in Table 3.

4 Conclusion

WSN deployments are constrained by the coverage and performances of the devices' RAT. The use of several RAT allows to overcome these shortcomings. In this article, we show the feasibility and utility of MTN and we overview the Routing Over Different Existing Network Technologies protocol (RODENT). It is designed for routing in MTN and enable the use of multi-technologies routes. For future works, we plan to precisely measure the energy savings and extend RODENT to support downlink communication. We plan to conceive an efficient link layer protocol for accurate link costs and performances assessment for multi-RAT.

5 Acknowledgments

This work was partially supported by a grant from CPER DATA, Sencrop, FEDER, I-SITE and Lirima Agrinet project. I would like to express my gratitude to my advisor Dr. Nathalie Mitton for her valuable comments and suggestions to improve this work.

6 References

[1] B. Foubert and N. Mitton. Autonomous Collaborative Wireless Weather Stations: A Helping Hand for Farmers. ERCIM News, (119), 2019.

[2] B. Foubert and N. Mitton. Long-range wireless radio technologies: A survey. Future Internet, 12(1), 2020.

[3] B. Foubert and N. Mitton. Sélection d'interface de communication dans les réseaux de capteurs multi-technologies. In CoRes, 2020.

[4] D. Ye, D. Gong, and W. Wang. Application of wireless sensor networks in environmental monitoring. In PEITS, 2009.

7 Author biography

Brandon Foubert received a Master's degree in Computer Networks and Embedded Systems from the University of Strasbourg in 2018. He investigated "Cooperation between multiple RPL networks" under the direction of Julien Montavont in the Network research group from the ICube laboratory. He is currently pursuing a PhD degree under the supervision of Nathalie Mitton in the FUN team at Inria Lille - Nord Europe since September 2018 and until September 2021. He is studying "Polymorphic wireless communication for connected agriculture".